DECLARATION

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that I know well both the Japanese and English languages;

that to the best of my knowledge and belief the English translation attached hereto is a true and correct translation of Japanese Patent Application No. 2002-303036, filed on October 17, 2002;

that all statements made of my own knowledge are true;

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Dated: August 4, 2008

Masato Sasaki

Masato Sasaki

[Document Name]	Petition for Patent
[Reference Number]	1021507
[Filing Date]	October 17, 2002
[Destination]	To the Commissioner of the JPO
[International Class]	C21D 1/18 C23C 8/32 F16C 33/30
[Inventor]	
[Address]	c/o NTN Corporation, 3066, Aza Oyumida, Oaza Higashikata, Kuwana-shi, Mie
[Name]	Kikuo MAEDA
[Inventor]	
[Address]	c/o NTN Corporation, 3066, Aza Oyumida, Oaza Higashikata, Kuwana-shi, Mie
[Name]	Yukio FUJII
[Inventor]	
[Address]	c/o NTN Corporation, 1578, Higashikaizuka, Iwata-shi, Shizuoka
[Name]	Kenichi ICHIKAWA
[Applicant]	
[Identification Number]	000102692
[Address]	3-17, Kyomachibori 1-chome, Nishi-ku, Osaka-shi
[Name]	NTN Corporation
[Attorney]	

[Identification Number] 100064746

[Patent Attorney]

[Name] Hisao FUKAMI

[Appointed Attorney]

[Identification Number] 100085132

[Patent Attorney]

[Name] Toshio MORITA

[Appointed Attorney]

[Identification Number] 100083703

[Patent Attorney]

[Name] Gihei NAKAMURA

[Appointed Attorney]

[Identification Number] 100096781

[Patent Attorney]

[Name] Yutaka HORII

[Appointed Attorney]

[Identification Number] 100098316

[Patent Attorney]

[Name] Hisato NODA

[Appointed Attorney]

[Identification Number] 100109162

[Patent Attorney]

[Name] Masayuki SAKAI

[Appointed Attorney]		
[Identification Number]	100111936	
[Patent Attorney]		
[Name]	Seiichi WATANABE	
[Indication of Fee]		
[Deposit Account Number]	008693	
[Fee]	21000	
[List of the Accompanying Documents]		
[Document]	Specification	1
[Document]	Drawings	1
[Document]	Abstract	1

[Document Name] Specification

[Title of the Invention] Full-Type Rolling Bearing

[Scope of Claims for Patent]

1. A full-type rolling bearing formed of an outer ring, an inner ring and rollers that are made of steel, wherein

at least one of said outer ring, inner ring and rollers has a carbonitrided layer in its surface layer, and the austenite crystal grain size number of the surface layer is at least a prescribed rate.

2. The full-type rolling bearing according to claim 1, wherein

at least one of said outer ring, inner ring and rollers is carbonitrided at a carbonitriding temperature equal to or higher than the A1 transformation temperature, cooled to a temperature lower than the A1 transformation temperature and then heated to a quenching temperature lower than said carbonitriding temperature and thereby quenched.

3. The full-type rolling bearing according to claim 1 or 2, wherein

said quenching temperature is in a temperature range at which carbide and/or nitride and an austenite phase coexist in the carbonitrided surface layer of the steel.

4. The full-type rolling bearing according to claim 2 or 3, wherein

said quenching temperature is 790°C - 830°C.

5. The full-type rolling bearing according to any of claims 2 to 4, wherein

at least one of said outer ring, inner ring and rollers is cold-worked before being carbonitrided.

6. The full-type rolling bearing according to any of claims 1 to 5, wherein

said austenite crystal grain size number is at least 11.

7. The full-type rolling bearing according to any of claims 1 to 6, wherein

in at least one of said outer ring, inner ring and rollers, a compression residual stress of at least 500 MPa is generated.

[Detailed Description of the Invention]

[Technical Field to Which the Invention Belongs]

The present invention relates to a material for full-type rolling bearings that have no cage, such as bearings for rocker arms, cam followers and roller follower bearings.

[Prior Art]

Of recent rolling bearings, full-type roller bearings without cage like bearings for rocker arms to be used for high-speed heavy-load applications are increasing in number. The full-type roller bearing herein refers to a bearing without cage as described above and may sometimes be abbreviated as full roller bearing. In the full-type roller bearing without cage, it inevitably occurs that rollers interfere with each other. Therefore, at high speeds, rollers suffer surface damages or rollers are not properly controlled in terms of their positions so that skew is likely to occur. Resultant heat generation due to sliding as well as a local increase in surface pressure are likely to cause such surface damages as peeling, smearing, surface-initiated peeling as well as inside-initiated peeling.

More specifically, in such full-type roller bearings as roller follower, cam follower and rocker arm, the interference between rollers and poor supply of lubricant into the bearings could cause peelings initiated from the surfaces of rollers and raceways. Moreover, influences of an assembly error and a biasing load could cause skew of rollers, resulting in surface-initiated peelings due to sliding and inside-initiated peelings due to a local increase in surface pressure.

For such an application as rocker arm that has an outer ring with its circumference being in rolling contact with a cam, most improvements have been made for the purpose of improving the circumference of the outer ring. On the other hand, compression stress induced by such a process as shot peening and increased hardness induced by high-concentration carbonitriding (process-induced hardening) have been used for prolonging the lifetime, chiefly for improving the circumference of the outer ring that is in rolling contact with the cam. In contrast, there have been few improvements for prolonging the rolling lifetime of the inner ring, roller or the whole bearing. As described below, some improvements have still been made in terms of

materials for providing heat resistance and microstructure stability as well as increased hardness that are obtained through carbonitriding, and thereby prolonging the lifetime of the bearing.

There have been known techniques regarding extension of the lifetime of the rocker arm or the like as listed below:

(1) For a cam follower bearing of an engine valve mechanism, a calculated life of the bearing, at a rated engine rpm, of 1000 hours or longer is achieved (see Patent Document 1).

(2) In order to achieve a bearing shaft of a cam follower with the properties of: a carbide ratio = 10-25 %; ratio of decomposed austenite content to initial retained austenite content = 1/10 - 3/10; end hardness = HV 830 - 960; and average wavelength of surface roughness = 25 μm or less, a bearing steel is carbonitrided and hard shot peened (see Patent Document 2).

(3) A solid lubricant film of high polymer for example is formed on a cam follower shaft for improving wear resistance of the shaft (see Patent Document 3).

(4) A cam follower shaft is made of a tool steel for example and is ion-nitrided or ion-plated at a temperature lower than a tempering temperature so as to have a high hardness (see Patent Document 4).

(5) A cam follower bearing for an engine valve mechanism that has its shaft for which a bending stress is 150 MPa or less (see Patent Document 5).

(6) A cam follower for an engine valve mechanism that has a phosphate film which is excellent in lubricating-oil retention and provided on a rolling surface of a bearing component (see Patent Documents 6, 7).

(7) A cam follower for an engine valve mechanism that has a crowning in a region of a shaft where rollers roll (see Patent Document 8).

(8) A carburized shaft has a rolling surface layer which is high-concentration carburized or carbonitrided with a carbon concentration of 1.2% - 1.7% and has an internal hardness of HV 300 (see Patent Document 9).

[Patent Document 1]

Japanese Patent Laying-Open No. 2000-38907

[Patent Document 2]

Japanese Patent Laying-Open No. 10-47334

[Patent Document 3]

Japanese Patent Laying-Open No. 10-103339

[Patent Document 4]

Japanese Patent Laying-Open No. 10-110720

[Patent Document 5]

Japanese Patent Laying-Open No. 2000-38906

[Patent Document 6]

Japanese Patent Laying-Open No. 2000-205284

[Patent Document 7]

Japanese Patent Laying-Open No. 2002-31212

[Patent Document 8]

Japanese Utility-Model Laying-Open No. 63-185917

[Patent Document 9]

Japanese Patent Laying-Open No. 14-194438

[Problems to be Solved by the Invention]

It is assumed that, the full-type roller bearings like the rocker arm, roller follower and cam follower will, similar to normal caged bearings, increase in speed and load in use, and the viscosity of a lubricating oil therefor will decrease. In order to extend the rolling life of the full-type roller bearings under such conditions in use, (a1) any measure should be taken, as usually done, for the rolling fatigue life dependent on the load and (a2) any measure should further be taken for the surface damage life due to metal contact caused by sliding and loss of an oil film. However, there has been no technique for remarkably extending both of the rolling fatigue life dependent on the load and the surface damage life due to the metal contact. Moreover, in addition to these two

measures for prolonging the life, (a3) any measure should be taken for the issue of shortening of the life due to the interference of rollers with each other as well as the skew thereof that are peculiar to the full-type roller bearings.

The above-described known techniques improve the rolling life by increasing the hardness and the compression residual stress, or improve the rolling surface where a bearing component is in rolling contact with a counterpart component. In actually evaluating these techniques, it is found that they are effective for extending the life in such an application where bending is applied as in the case of the outer ring, while such improvements are not necessarily effective by themselves for extending the life of the inner ring and rollers of the full roller bearing.

An object of the present invention is, in consideration of the increased speed and load in use and the decreased viscosity of the lubricating oil, to provide a full-type rolling bearing that exhibits a long life under severe lubrication, sliding and load conditions.

[Means for Solving the Problems]

A full-type rolling bearing according to the present invention is formed of an outer ring, an inner ring and rollers that are made of steel, at least one of the outer ring, inner ring and rollers has a carbonitrided layer in its surface layer, and the austenite crystal grain size number of the surface layer is at least a prescribed value.

For the full-type rolling bearing of the present invention, a material with fine crystal grains and heat resistance can be used to extend the surface damage (surface-initiated exfoliation like peeling and smearing) life as well as the inside-initiated peeling life. Specifically, processing of such a material as bearing steel or heat treatment pattern is improved to produce a carbonitrided structure ensuring an austenite crystal grain size number of at least a certain value, for example, at least 9 or at least 11 in the case where it is a prescribed value. The resultant structure can remarkably enhance the resistance to occurrence and development of cracks. Accordingly, heat generation of the surface layer due to sliding and occurrence of surface cracks due to tangential force

can be prevented. Moreover, against cracks resulting from inside-initiated peelings, the life can remarkably be extended.

The above-described microstructure is further processed and heat-treated and a compression stress is imposed on the surface layer to increase the hardness, so that the life can further be extended. The processing and heat treatment may be any one of, or a combination of: (b1) shot peening, (b2) barrel finishing, (b3) rolling, (b4) varnishing, (b5) carburizing and carbonitriding, (b6) carbonitriding and sub-zero treatment, and (b7) carbonitriding and secondary quenching and sub-zero treatment.

Here, the austenite crystal grain size number of at least a prescribed value means that the degree of fineness of the austenite crystal grains is specified to, for example, the grain size number of at least 7, at least 8, at least 9, at least 10, larger than 10 or at least 11, as determined according to a method of testing the austenite crystal grain size defined under JIS G 0551.

At least one of the outer ring, inner ring and rollers may be carbonitrided at a carbonitriding temperature equal to or higher than the A1 transformation temperature, cooled to a temperature lower than the A1 transformation temperature and heated to a quenching temperature lower than the carbonitriding temperature and thereby quenched.

Such a microstructure is once cooled to a temperature lower than the carbonitriding temperature and then quenched from the resultant quenching temperature so that considerably fine austenite crystal grains can be obtained. This process of quenching by heating to a temperature lower than the carbonitriding temperature is sometimes called, in terms of the order of the process, secondary quenching or final quenching.

The quenching temperature may be in a temperature range at which carbide and/or nitride and an austenite phase coexist in the carbonitrided surface layer of the steel.

The quenching temperature is lower than the carbonitriding temperature, and thus the amount of un-dissolved carbide and/or nitride in the surface layer, which is

influenced by the carbonitriding process, increases as compared with that in the carbonitriding process. Then, when the quenching temperature is in the temperature range where those components coexist, the ratio of un-dissolved carbide/nitride increases while the ratio of austenite decreases at the quenching temperature as compared with those ratios in the carbonitriding process. In addition, it is seen from the Fe-C binary phase diagram that, in the range where carbide (cementite) and austenite coexist, the concentration of carbon dissolved in austenite decreases as the quenching temperature decreases. As the steel for the bearing has low contents of other alloy elements like Si and Mn, the temperature region and the generated layer can be discussed with sufficient precision with reference to the Fe-C binary phase diagram. In addition, nitrogen, like carbon, is an interstitial element dissolved in iron and produces nitride with iron similar to cementite in a predetermined temperature region, and the nitrogen can be regarded approximately as the same as carbon.

When the temperature is increased to the quenching temperature, austenite grains are made fine since there remain a large amount of un-dissolved carbide and/or nitride that prevent growth of austenite grains. Moreover, the structure transformed from austenite to martensite through quenching has a somewhat low carbon concentration when the above-described heat treatment is applied, so that the structure has somewhat high toughness as compared with the structure quenched from the carbonitriding temperature. In other words, the quenched structure has (c1) a greater amount of un-dissolved carbide/nitride as compared with the structure produced through the conventional process, and (c2) a lower carbon concentration than the conventional one.

The above-discussed quenching temperature may be 790°C - 830°C. This temperature is applicable to most of steel materials to facilitate management of the sintering temperature.

Further, at least one of the outer ring, inner ring and rollers may be cold-worked before being carbonitrided.

The cold-working can be applied to increase the nucleation density of austenite grains in the heat treatment and thereby produce a fine-grain structure.

The austenite may have the grain size number of at least 11. With the defined austenite grain size, austenite grains that are extremely and unthinkably fine austenite grains contribute to achievement of stably long rolling fatigue life and surface damage life. Moreover, the issue of the decreased viscosity of the lubricating oil can satisfactory be addressed.

In at least one of the outer ring, inner ring and rollers, a compression residual stress of at least 500 MPa may be generated.

As discussed above, the microstructure can further be processed and heat-treated and a compression residual stress can be applied to the surface layer so as to further extend the life.

[Embodiments of the Invention]

Embodiments of the present invention are hereinafter described in connection with the drawings. Fig. 1 is a schematic front view showing a structure of a rocker arm according to an embodiment of the present invention, and Fig. 2 is a cross-sectional view along line II-II in Fig. 1. Referring to Figs. 1 and 2, a cam follower body 1 is pivotably supported, at a central part, on a cam follower shaft 5 via a bearing metal for example.

An adjust screw 7 is screwed into one end of this cam follower body 1. Adjust screw 7 is fixed by a lock nut 8 having its lower end abutting on the upper end of a projecting pole 9 of an intake valve or discharge valve of an internal-combustion engine. Projecting pole 9 is biased by elasticity of a spring 10.

Cam follower body 1 has the other end provided with a bifurcated roller supporting portion 14 which is formed integrally with the body. In bifurcated roller supporting portion 14, both ends of roller shaft 2 are press-fit or fixed by means of a snap ring. On a central part of the outer surface of roller shaft 2, an outer ring 4 is supported rotatably via rollers 3. The outer surface of outer ring 4 is brought into

contact with the surface of cam 6 by the biasing force of spring 10.

Here, the rolling bearing including an inner ring formed of roller shaft 2, rolling elements formed of rollers 3 and outer ring 4 is employed as a rocker arm bearing. Of roller shaft 2, outer ring 4 and rollers 3 constituting the rocker arm bearing, at least one member has its surface layer where a carbonitrided layer is formed, and the surface layer has an austenite crystal grain size number of at least 9 or at least 11 in a prescribed case.

As the rocker arm bearing rotates while contacting cam 6, the pressing force and impact force of cam 6 are exerted on outer ring 4, possibly resulting in indentations and cracks due to repeated bending stress. In particular, with the increased engine output, the engine rpm accordingly increases so that those forces become greater resulting in a higher risk of occurrence of cracks and indentations and thus shortening of the rolling life and surface damage life.

Indentations due to exertion of a great force on the bearing are likely to be formed on the inner ring since the surface pressure between the inner ring and the rolling elements (rollers) is usually higher than the surface pressure between the outer ring and the rolling elements (rollers). For the cam follower, however, the bending stress is exerted on the outer ring while the high surface-pressure load is also exerted on the outer ring, and thus indentations are likely to be formed between the outer ring and the rolling elements. The inventors of the present invention have found that the surface damage life and the rolling life can be prolonged by forming a carbonitrided layer in a surface layer of at least one of the above-discussed components, with the austenite grain size number of the surface layer being at least 9 for example or at least 11 in a predetermined case. In addition, the inventors have found that the extent to which the life is prolonged is increased by adding a compression residual stress to the surface layer.

A carbonitrided layer in which austenite crystal grains are made fine is preferably produced by a method for example described below, however, any method except for this may be used. Fig. 3 exemplarily shows a heat treatment method for producing a carbonitrided layer having fine austenite crystal grains therein according to the present

invention, and Fig. 4 shows a modification thereof. Specifically, Fig. 3 shows a heat treatment pattern according to which primary quenching and secondary quenching are carried out, and Fig. 4 shows a heat treatment pattern according to which a material is cooled to a temperature lower than the A1 transformation temperature in a quenching process and thereafter heated again to be finally quenched. Referring to these drawings, in process T1, carbon and nitrogen are diffused through a steel matrix while the carbon is sufficiently dissolved therein, and thereafter cooling is done to a temperature below the A1 transformation temperature. Then, in process T2 shown in the drawings, heating is done again to a temperature lower than that in process T1 and then oil-quenching is performed. In process T1, a surface layer may be heated to a temperature in a range where austenite, carbide and/or nitride coexist. At a temperature in this coexistence region where austenite, carbide and/or nitride are present, austenite grains are fine and the concentration of carbon (nitrogen) in the austenite is relatively low. Therefore, even if quenching is conducted, a quenched structure which is sufficiently tough can be produced.

Compared with ordinary or normal quenching by which carbonitriding is done and immediately thereafter quenching is done once, the above-discussed heat treatment can improve the crack strength and prolong both of the surface damage life and the rolling fatigue life while carbonitriding the surface layer. Moreover, the issue of the decreased viscosity of the lubricating oil can be addressed. This heat treatment can also produce a microstructure having austenite crystal grains of a grain size which is smaller than the conventional one by one half or more. A bearing component undergoing this heat treatment has a long rolling fatigue life and a long surface damage life and can address the issue of decreased viscosity.

Fig. 5 shows a microstructure of a bearing component, particularly austenite grains. Fig. 5 (a) shows a bearing component of the present invention and Fig. 5 (b) shows a bearing component of a conventional bearing component. Namely, Fig. 5 (a) shows a grain size of austenite of a bearing steel having been heat-treated as shown in

Fig. 3. For comparison, Fig. 5 (b) shows a grain size of austenite of a bearing steel which has undergone the conventional heat treatment. Figs. 6 (a) and 6 (b) diagrammatically show the grain sizes of austenite that are shown in Figs. 5 (a) and 5 (b). In the structures with the crystal grain sizes of austenite, the grain diameter of the conventional austenite is 10 which is a grain size number defined by JIS while that of the present invention through the heat treatment thereof is 12 and thus fine grains are seen. Further, the average grain diameter in Fig. 8A is 5.6 μm measured by the intercept method. With a quenching temperature of 830°C, the average grain diameter is approximately 8 μm.

[Examples]

Bearings that were used for tests were full-type needle bearings. An inner ring (shaft) was 14.64 mm in outer diameter × 17.3 mm in width, an outer ring was 18.64 mm in inner diameter × 24 mm in outer diameter × 6.9 mm in width, and a roller was 2 mm in diameter and 6.8 mm in length. 26 rollers were used in a full-type structure. The bearings had a basic load rating of 8.6 kN and a basic static load rating of 12.9 kN. Here, basically the bearings were each a combination of the same materials, while some were each a combination of different materials and some were produced by being additionally processed.

Table 1 shows a list of the prepared bearings. Details of samples are as follows. It is noted that the inner ring, the outer ring and rollers were subjected to the same heat-treatment and processing, except for any case particularly noted.

Table 1 List of Test Samples

examples	No.	features	crystal grain size No.	surface layer hardness (HV)	compression residual stress (MPa)	500℃ tempering hardness (HV)
example *1	1	bearing steel: heavy cold working ＋ carbonitriding	11	750	200	620
	2	bearing steel: carbonitriding ＋low-temperature secondary quenching	12	770	150	580
	3	carburizing steel: carbonitriding ＋ low-temperature secondary quenching	11	770	350	650
	4	No.1 ＋ shot peening for inner and outer rings, barrel finishing for rollers	11	820	650	610
	5	No.2 ＋ shot peening for inner and outer rings, barrel finishing for rollers	12	800	600	590
	6	No.3 ＋ shot peening for inner and outer rings, barrel finishing for rollers	11	800	700	640
	7	No.1 ＋ sub-zero treating	11	850	100	610
	8	No.7 ＋ shot peening for inner and outer rings, barrel finishing for rollers	11	890	650	610
	9	carbonitriding and low-temperature secondary quenching for inner ring and rollers, normal heat treatment for outer ring	outer ring: 9 others: 12	outer ring: 740 others: 760	outer ring: 0 others: 150	outer ring: 470 others: 590
	10	carbonitriding and low-temperature secondary quenching of carburizing steel for inner and outer rings, carbonitriding for rollers	inner/outer rings: 11 rollers: 8	inner/outer rings: 760 rollers: 780	inner/outer rings: 350 rollers: 150	inner/outer rings: 650 rollers: 590
comparative example	11	normal heat treatment of bearing steel for inner and outer rings and rollers	10	740	0	470
	12	carbonitriding of bearing steel for inner and outer rings and rollers	8-9	780	180	580
	13	normal carburizing of carburizing steel for inner and outer rings, normal heat treatment of bearing steel for rollers	inner/outer rings: 7 rollers: 10	730	inner/outer rings: 400 rollers: 0	inner/outer rings: 460 rollers: 470
	14	secondary quenching of carburizing steel	10	750	200	470
	15	No.11 ＋ shot peening for inner and outer rings, barrel finishing for rollers	10	800	500	470

*1 examples of the present invention

No. 1: A bearing steel was subjected to heavy cold working in advance, heat-treated with crystal grains thereafter being made fine, and then carbonitrided (example of the present invention).

No. 2: A bearing steel was carbonitrided, then quenched and secondary-quenched at a temperature lower than the carbonitriding temperature (example of the present invention).

No. 3: A carburizing steel was carburized, carbonitrided and quenched, and then secondary-quenched at a lower temperature (example of the present invention).

The crystal grain size of austenite of those samples was at least No. 11 according to the aforementioned JIS testing method. These materials were used as base samples. The following samples were prepared by additionally processing the base samples for producing a compression residual stress in the surface layer.

No. 4: The inner and outer rings of sample No. 1 were shot-peened and rollers were barrel-finished (example of the present invention).

No. 5: The inner and outer rings of sample No. 2 were shot-peened and rollers were barrel-finished (example of the present invention).

No. 6: The inner and outer rings of sample No. 3 were shot-peened and rollers were barrel-finished (example of the present invention).

Samples with their surface hardness increased were prepared as follows.

No. 7: The inner and outer rings of sample No. 1 were additionally sub-zero treated (−196°C) (example of the present invention).

No. 8: The inner and outer rings of sample No. 1 were additionally sub-zero treated (−196°C) and then shot-peened, and rollers were barrel-finished (example of the present invention).

For the elements, the inner and outer rings and rollers, the above-described methods were applied to the inner and outer rings and rollers each, especially the inner ring and rollers for which the rolling life was significant.

No. 9: The inner ring and rollers were carbonitrided, quenched, and then

secondary-quenched at a temperature lower than the carbonitriding temperature, and the outer ring was subjected to a normal heat treatment (example of the present invention).

No. 10: For inner and outer rings, a carburizing steel was carburized, carbonitrided, cooled, and then secondary-quenched at a lower temperature than that of the carbonitriding temperature and, for rollers, a bearing steel was carbonitrided (example of the present invention).

As comparative examples, five samples were prepared as shown in the lower part of Table 1.

No. 11: Inner and outer rings and rollers were made of a bearing steel which was normally heat-treated (comparative example).

No. 12: Inner and outer rings and rollers were made of a bearing steel which was carbonitrided (comparative example).

No. 13: Inner and outer rings were made of a carburizing steel which was carburized and rollers were made of a bearing steel which was normally heat-treated (comparative example).

No. 14: This sample was made of a carburizing steel which was secondary-quenched (comparative example).

No. 15: Inner and outer rings of sample No. 11 were shot-peened and rollers thereof were barrel-finished (comparative example).

For materials for these samples, crystal grain size, hardness and hardness after 500°C-tempering (index of heat resistance) were measured, resultant measurements being shown in Table 1.

For the above-described samples, rolling fatigue test and surface damage strength test were evaluated

(1) Rolling Fatigue Test

An outer ring (18.64 mm in inner diameter × 24 mm in outer diameter × 6.9 mm in width), an inner ring (shaft) (14.64 mm in outer diameter × 17.3 mm in width) and 26 rollers (2 mm in diameter × 6.8 mm in length) were assembled and then subjected

to a rolling test under a load of 2.58 kN, which is 30% of the basic load rating 8.6 kN. A rolling fatigue test machine shown in Fig. 7 was used and test conditions were those as shown in Table 2. This rolling fatigue test was done for rotation of the outer ring. The results are shown in Table 3.

Table 2

Rolling Life Test Conditions for Bearing

tester	life tester for outer ring rotation
test piece	rocker arm bearing assembly
load (N)	2580N (0.3C)
outer ring rpm	7000 rpm
lubricant	engine oil 10W-30
oil temperature	100℃
life	peeling life

Table 3

List of Test Results

examples	No.	features	relative rolling life (L50)
example *1	1	bearing steel: heavy cold working ＋ carbonitriding	3.0
	2	bearing steel: carbonitriding ＋low-temperature secondary quenching	3.5
	3	carburizing steel: carbonitriding ＋ low-temperature secondary quenching	3.2
	4	No.1 ＋ shot peening for inner and outer rings, barrel finishing for rollers	4.1
	5	No.2 ＋ shot peening for inner and outer rings, barrel finishing for rollers	3.9
	6	No.3 ＋ shot peening for inner and outer rings, barrel finishing for rollers	4.3
	7	No.1 ＋ sub-zero treating	2.8
	8	No.7 ＋ shot peening for inner and outer rings, barrel finishing for rollers	3.5
	9	carbonitriding and low-temperature secondary quenching for inner ring and rollers, normal heat treatment for outer ring	2.8
	10	carbonitriding and low-temperature secondary quenching of carburizing steel and bearing steel respectively for inner and outer rings and for rollers	3.1
comparative example	11	normal heat treatment of bearing steel for inner and outer rings and rollers	1.0
	12	carbonitriding of bearing steel for inner and outer rings and rollers	1.9
	13	normal carburizing of carburizing steel for inner and outer rings, normal heat treatment of bearing steel for rollers	1.2
	14	secondary quenching of carburizing steel	1.4
	15	No.11 ＋ shot peening for inner and outer rings, barrel finishing for rollers	1.7

*1 examples of the present invention

The peeling was mainly occurred on the rollers or the inner ring, which is not shown in Table 3. The peeling was also occurred partially on the outer ring of sample No. 9 (example of the present invention). It is seen from Table 3 that the samples of the present invention exhibit a longer life as compared with the comparative examples and any samples of the present invention exhibit a lifetime which is approximately three times as long as that of the normally processed sample and approximately 1.5 times as long as the carbonitrided sample.

(2) Peeling Test

Table 4 shows peeling test conditions and Table 5 shows a list of test samples.

Table 4

Peeling Test Results

tester	ring to ring type tester
test piece	ϕ 40 straight, surface roughness (Rt) 0.2 μ m
counterpart test piece	ϕ 40 $\times$ R60, surface roughness (Rt) 3.0 μ m (made of SUJ2)
contact surface pressure	Pmax 2.3 GPa
lubricating oil	turbine oil VG46
rotational speed of counterpart test piece	2000 rpm (test piece rolls following rotation of counterpart test piece)
total load count	4.8×10^5 times

Table 5

List of Test Samples

examples	No.	features	peeling strength	relative peeling strength	relative crack strength	relative crack fatigue strength
example *1	1	bearing steel: heavy cold working ＋ carbonitriding	1.7	1.6	1.2	1.2
	2	bearing steel: carbonitriding ＋low-temperature secondary quenching	1.8	1.7	1.1	1.2
	3	carburizing steel: carbonitriding ＋ low-temperature secondary quenching	1.5	1.5	1.0	1.3
	4	No.1 ＋ shot peening	2.0	1.8	1.3	1.3
	5	No.2 ＋ shot peening	2.1	1.9	1.2	1.3
	6	No.3 ＋ shot peening	2.0	1.8	1.2	1.4
	7	No.1 ＋ sub-zero treating	1.8	1.6	1.1	1.0
	8	No.7 ＋ shot peening	2.0	1.8	1.3	1.2
comparative example	11	normal heat treatment of bearing steel	1.0	1.0	1.0	1.0
	12	carbonitriding of bearing steel	1.4	1.5	0.8	1.1
	13	normal carburizing of carburizing steel	0.8	0.9	0.7	1.2
	14	secondary quenching of carburizing steel	1.1	1.1	0.9	1.1
	15	No.11 ＋ shot peening	1.1	1.0	1.1	1.0

*1 examples of the present invention

A peeling test was conducted on total eight types of materials of examples of the present invention including No. 1 to No. 3 as well as the same for which shot peening and sub-zero treatment were performed (No. 1 to No. 8), and five types of materials of comparative examples (No. 11 to No. 15), namely total 13 types of materials. Test pieces (mirror-finished) having a diameter of 40 mm were brought into rolling contact with a rough-surfaced counterpart test piece made of SUJ2 under constant conditions, and the ratio of an area where peelings, namely a collection of fine peelings, were observed on the (mirror-finished) test piece of a sample to the entire area was measured after a certain time. The reciprocal of the determined ratio of the area is herein defined as peeling strength, and the peeling strength of a normal sample (comparative example No. 11) is indicated by 1 as a reference. Table 5 shows the results.

According to Table 5, the examples of the present invention have a peeling strength which is at least 1.5 times as high as that of comparative examples. It is seen that the fineness of the crystal grains and appropriate retained austenite enhance the toughness and thereby increase resistances against occurrence and subsequent growth of cracks. Moreover, samples (No. 4-8) with a compression residual stress provided through the sub-zero treatment and any processing are improved in terms of strength. This is because the high hardness and the compression residual stress effectively contribute to prevention of occurrence and growth of peeling cracks.

(3) Smearing Test

The same test pieces as those for the peeling test were used to examine smearing strength. Test conditions are shown in Table 6.

Table 6

Smearing Test Conditions

tester	ring to ring type tester
test piece	ϕ 40×R60 surface roughness (Rt) 3.0 μ m
counterpart test piece	ϕ 40×R60 surface roughness (Rt) 3.0 μ m
contact surface pressure	Pmax 2.1 GPa
lubricating oil	turbine oil VG46
rotational speed of counterpart test piece	200 rpm, acceleration of 100 rpm per 30 sec
rotational speed of test piece	200 rpm

A test piece to be tested and a counterpart test piece were each made of a combination of the same materials. The results are shown in Table 5. Here, the evaluation is based on the rotational speed of the counterpart test piece when smearing occurred, and shown as a ratio with respect to the result of the normal sample (comparative example No. 11) which was used as a reference. With regard to smearing as well, it is also observed that the smearing strength (rotational speed before the smearing occurs) of the examples of the present invention is at least 1.5 times as high as that of the normal sample of the comparative example and is somewhat higher than the smearing strength of other comparative examples. The balance established between the fineness of the crystal grains, an appropriate amount of retained austenite and the presence of fine carbide prevents plastic flow of the surface layer and accordingly improves the anti-seizure property. Samples that were additionally processed exhibit a slight improvement in strength compared with samples without being additionally processed.

(4) Static Crack Strength:

For test samples shown in Table 5, crack strength was measured by imposing a load by an Amsler's testing machine on only an outer ring (18.64 mm in inner diameter × 24 mm in outer diameter × 6.9 mm in width) as shown in Fig. 8. Results are shown in Table 5.

Origins of cracks were on the inner surface of the ring (rolling contact surface). Table 5 shows that the carbonitriding usually deteriorates the static crack strength as seen from comparative example No. 12. In contrast, the static strength of examples Nos. 1-3 of the present invention is equal to or somewhat higher than that of the normal sample undergoing the normal heat treatment and the examples of the present invention do not show deterioration in static crack strength. Examples Nos. 4-6 of the present invention that are additionally processed as compared with examples Nos. 1-3 are all enhanced in crack strength. Example No. 7 of the present invention undergoing sub-zero treatment is slightly lower in static crack strength than example No. 1 without being sub-zero treated, and is slightly higher in static crack strength than example No. 8 which is additionally processed as compared with example No. 7.

It is considered that a reason for the deterioration of the strength of comparative example No. 12 is an increased crystal grain size and an increased amount of retained austenite resulting from a long-term diffusion process of the carbonitriding so that a structure having a low tensile strength is locally formed. Comparative example No. 13 also deteriorates in strength for the same reason.

(5) Crack Fatigue Strength:

Crack fatigue strength was determined by repeatedly imposing a load under conditions shown in Table 7 on an outer ring of the samples shown in Table 5. Specifically, a load in the range from 98 N to a predetermined load was repeatedly exerted on the outer ring and the number of repetitions before cracks occurred was used for comparison.

Table 7

Ring Crack Fatigue Test Conditions

tester	hydraulic servo type vibrator
test piece	ϕ 18.64 $\times$ ϕ 24 $\times$ L6.9
load (N)	changing in the range of 3000-5000
load frequency (Hz)	20-50 (changing depending on load)
evaluation	strength at 10^5 times on S/N curve

Here, the load conditions were changed and the load was repeatedly applied to determine a load applied 10^5 times that the sample endures. Results are shown in Table 5 as crack fatigue strength. The reference used for determining the ratio of the strength is here the strength of the normal heat-treated sample of the comparative example. Any examples of the present invention are remarkably improved in crack fatigue strength.

Regarding the crack fatigue strength, example No. 3 of the present invention having the carburizing steel as the base component and example No. 6 of the present invention with the carburizing steel as the base component to which the compression residual stress is added are superior in strength.

It is accordingly found from the above results that the rolling life can remarkably be improved for the rolling bearing that is likely to have a short life due to adverse sliding conditions, skew of rollers and interference of rollers with each other, by implementing a microstructure including fine crystal grains and appropriate retained austenite. Further, this approach does not deteriorate the crack strength, as different from the conventional carbonitriding, so that a full-type rolling bearing with increased strength and life can be implemented.

Although the present invention has been described and illustrated in detail, it is clearly understood that the same is by way of illustration and example only and is not to be taken by way of limitation, the spirit and scope of the present invention being limited only by the terms of the appended claims.

[Effect of the Invention]

For the full-type rolling bearing of the present invention, a material having a carbonitride layer comprised of fine austenite grains is arranged to allow the full-type rolling bearing to be used under the conditions of high-speed, heavy-load and lowered viscosity of lubricating oil and ensure sufficient durability.

[Brief Description of the Drawings]

Fig. 1 shows a rocker arm bearing which is a full-type rolling bearing according

to an embodiment of the present invention.

Fig. 2 is a cross-sectional view along line II-II in Fig. 1.

Fig. 3 shows a heat treatment method according to the embodiment of the present invention.

Fig. 4 shows a heat treatment method according to a modification of the embodiment.

Fig. 5 show a microstructure, particularly prior austenite grains, of a bearing component, (a) showing a bearing component of the present invention and (b) showing a conventional bearing component.

Fig. 6 shows austenite grain boundaries at (a) and (b) corresponding respectively to Fig. 5 (a) and Fig. 5 (b).

Fig. 7 schematically shows a rolling fatigue life tester.

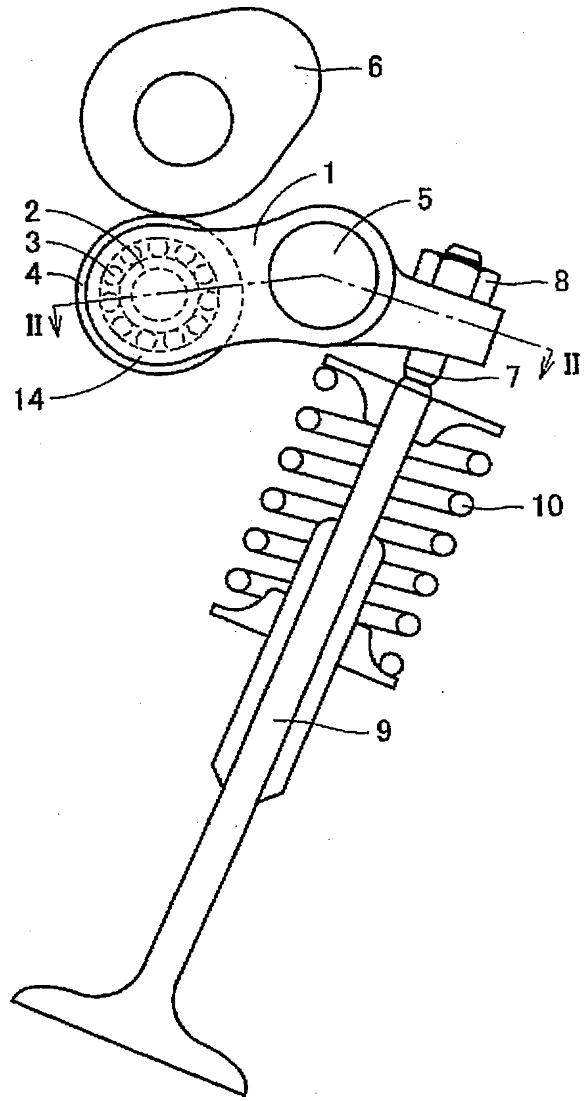
Fig. 8 shows a test piece for testing the static crack strength.

[Description of the Reference Characters]

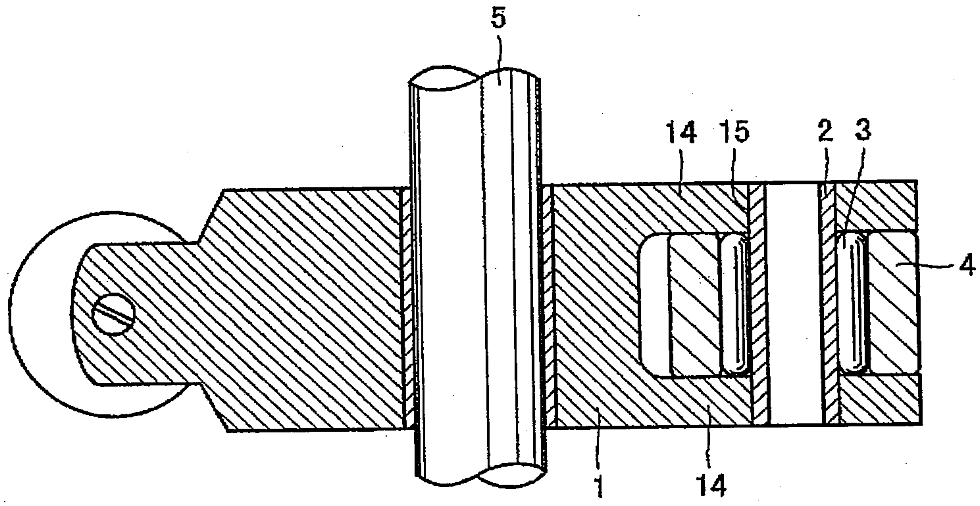
1 cam follower body, 2 roller shaft (inner ring), 3 needle-shaped roller (rolling element), 4 roller (outer ring), 5 cam follower shaft, 6 cam, 7 adjust screw, 8 lock nut, 9 projecting pole, 10 spring, 14 roller supporting portion, T1 carbonitriding (its heating temperature), T2 quenching (its heating temperature)

【書類名】　図面
DOCUMENT NAME　Drawings

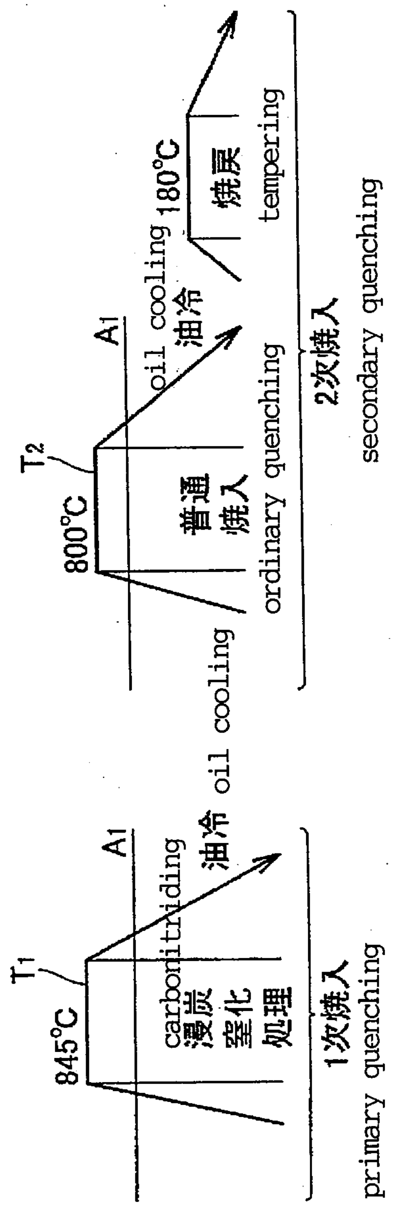
【図１】
Fig. 1



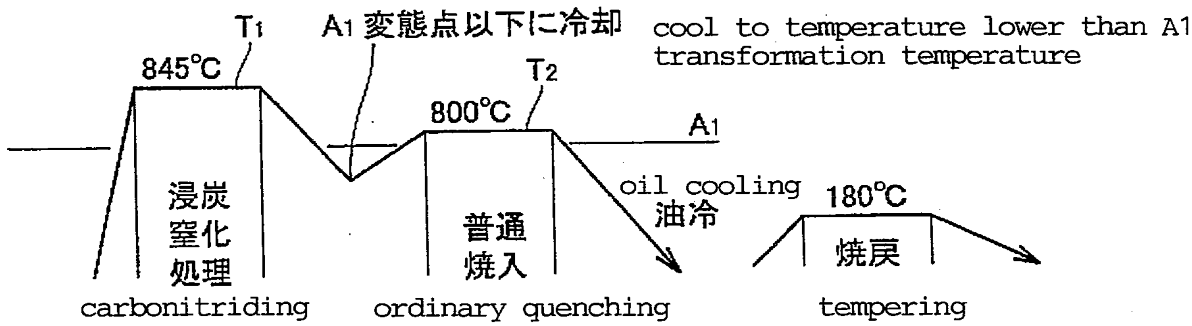
【図２】
Fig. 2



【図３】
Fig. 3

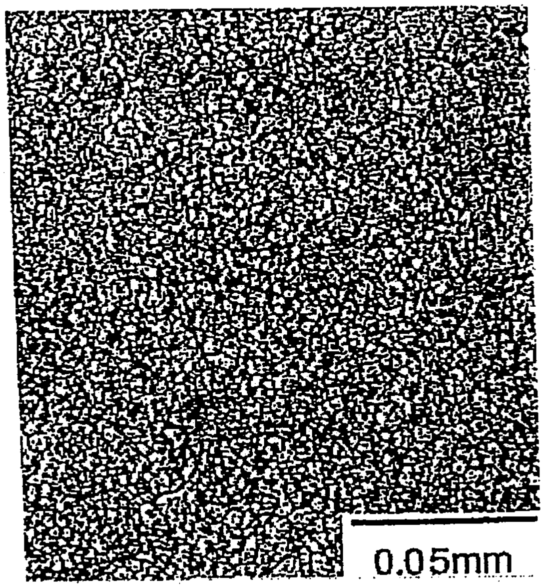


【図４】
Fig. 4

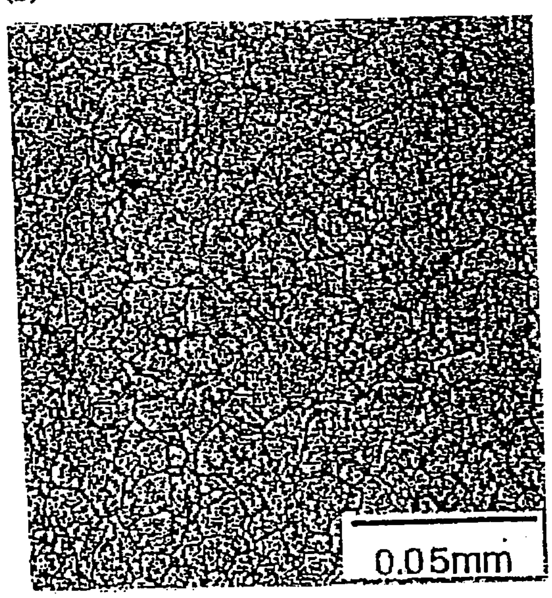


【図５】
Fig. 5

(a)



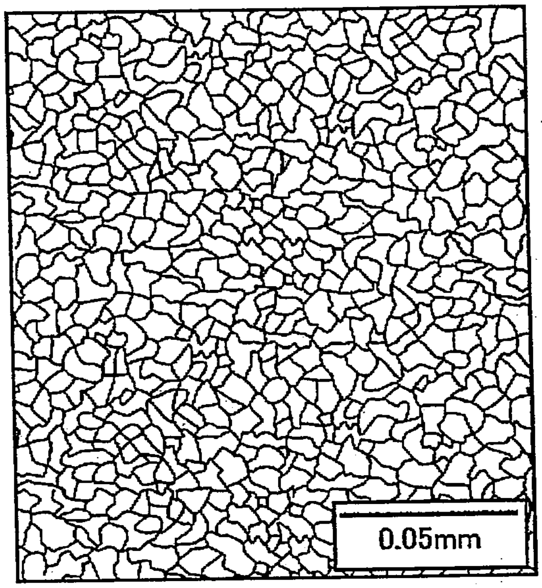
(b)



【図６】

Fig. 6

(a)



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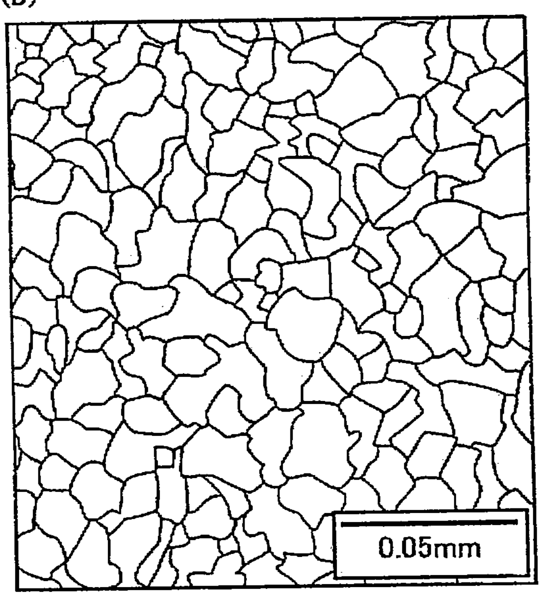
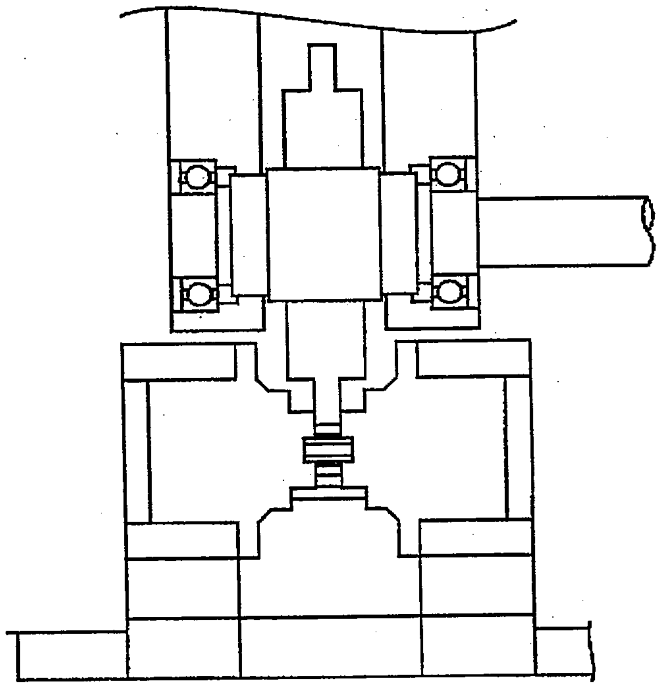
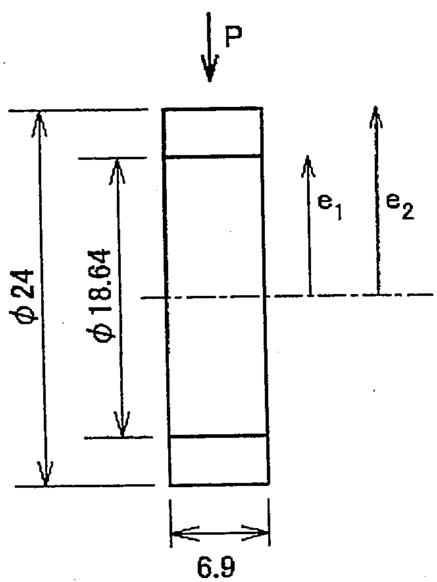


【図７】
Fig. 7



【図８】
Fig. 8



[Document Name] Abstract

[Abstract]

[Subject] A full-type rolling bearing that can be used under the conditions of high-speed, heavy-load and lowered viscosity of lubricating oil is provided.

[Solving Means] The full-type rolling bearing is formed of an outer ring 4, an inner ring 2 and rollers 3 made of steel, at least one of the outer ring, inner ring and rollers has a carbonitrided layer in its surface layer, and the austenite crystal grain size number of the surface layer is at least a prescribed value.

[Selected Drawing] Fig. 1